**Chapter 24 Section 3 The Sun**

**Key Concepts**

* [What is the structure of the sun?](javascript:openCrossRef('../ch24/ch24_s3_1.html%23lnk685.2'))
* [What are the characteristics of features on the sun?](javascript:openCrossRef('../ch24/ch24_s3_2.html%23lnk687.1'))
* [How does the sun produce energy?](javascript:openCrossRef('../ch24/ch24_s3_3.html%23lnk689.3'))

**Vocabulary**

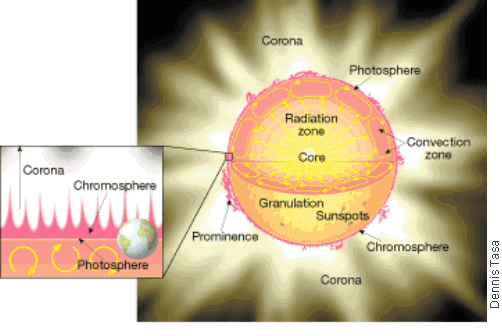
* [photosphere](javascript:openCrossRef('../ch24/ch24_s3_1.html%23lnk685.3')) [chromosphere](javascript:openCrossRef('../ch24/ch24_s3_1.html%23lnk686.1'))
* [corona](javascript:openCrossRef('../ch24/ch24_s3_1.html%23lnk686.2')) [solar wind](javascript:openCrossRef('../ch24/ch24_s3_1.html%23lnk686.3'))
* [sunspot](javascript:openCrossRef('../ch24/ch24_s3_2.html%23lnk687.3')) [prominence](javascript:openCrossRef('../ch24/ch24_s3_2.html%23lnk688.1'))
* [solar flare](javascript:openCrossRef('../ch24/ch24_s3_2.html%23lnk688.2')) [aurora](javascript:openCrossRef('../ch24/ch24_s3_2.html%23lnk688.3'))
* [nuclear fusion](javascript:openCrossRef('../ch24/ch24_s3_3.html%23lnk689.3'))

The sun is one of the 100 billion stars that make up the Milky Way galaxy. Although the sun is of no significance to the universe as a whole, it is Earth’s primary source of energy. Everything—from the fossil fuels we burn in our automobiles to the food that we eat—is ultimately derived from solar energy. The sun is also important to astronomers, since it is the only star whose surface we can study. Even with the largest telescopes, other stars appear only as points of light. Because of the sun’s brightness and its damaging radiation, it is not safe to observe it directly. However, a telescope can project its image on a piece of cardboard held behind the telescope’s eyepiece. In this manner, the sun can be studied safely. This basic method is used in several telescopes around the world, which keep a constant watch of the sun. One of the finest is at the Kitt Peak National Observatory in southern Arizona, shown in Figure 11. It consists of an enclosure with moving mirrors that directs sunlight to an underground mirror. From the mirror, an image of the sun is projected to an observing room, where it is studied.

**Figure 11 The McMath-Pierce Solar Telescope at Kitt Peak Near Tucson, Arizona** Movable mirrors at the top follow the sun, reflecting its light down the sloping tunnel.

Compared to other stars, the sun is an “average star.” However, on the scale of our solar system, it is truly gigantic. Its diameter is equal to 109 Earth diameters, or 1.35 million kilometers. Its volume is 1.25 million times as great as Earth’s. Its mass is 332,000 times the mass of Earth and its density is only one quarter that of solid Earth.

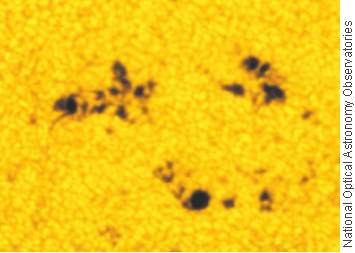
**Structure of the Sun**

Because the sun is made of gas, no sharp boundaries exist between its various layers. **Keeping this in mind, we can divide the sun into four parts: the solar interior; the visible surface, or photosphere; and two atmospheric layers, the chromosphere and corona.** These parts are shown in Figure 12. The sun’s interior makes up all but a tiny fraction of the solar mass. Unlike the outer three layers, the solar interior cannot be directly observed. Let’s discuss the visible layers first.

**Figure 12 Structure of the Sun** The sun can be divided into four parts: the solar interior, the photosphere, the chromosphere, and the corona.

**Photosphere**

The **[photosphere](javascript:openGlossaryWnd('e_ga_06_photosphere')" \o "ALT G, Glossary Term, link opens in new window)** (*photos* = light, *sphere* = a ball) radiates most of the sunlight we see and can be thought of as the visible “surface” of the sun. The photosphere consists of a layer of gas less than 500 kilometers thick. It is neither smooth nor uniformly bright, as the ancients had imagined.

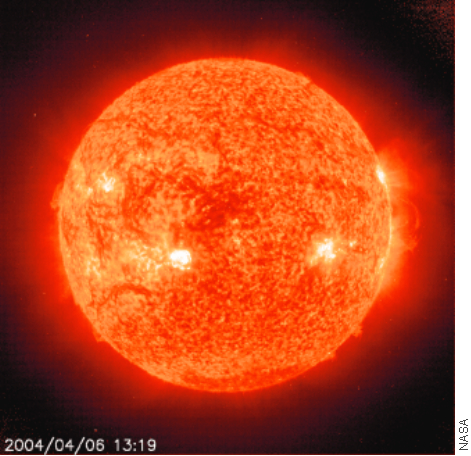
When viewed through a telescope, the photosphere’s grainy texture is apparent. This is the result of numerous relatively small, bright markings called granules, which are surrounded by narrow, dark regions, as shown in Figure 13. Granules are typically the size of Texas, and they owe their brightness to hotter gases that are rising from below. As this gas spreads, cooling causes it to darken and sink back into the interior. Each granule survives only 10 to 20 minutes. The combined motion of new granules replacing old ones gives the photosphere the appearance of boiling. This up-and-down movement of gas is called convection. Besides producing the grainy appearance of the photosphere, convection is believed to be responsible for the transfer of energy in the uppermost part of the sun’s interior.

**Figure 13 Granules** Granules are the yellowish-orange patches on the photosphere. **Describing**Describe the movement of gases in the convection zone.

The composition of the photosphere is revealed by the dark lines of its absorption spectrum. Studies reveal that 90 percent of the sun’s surface atoms are hydrogen, almost 10 percent are helium, and only minor amounts of the other detectable elements are present. Other stars also have high proportions of these two lightest elements, a fact we shall discuss later.

**Chromosphere**

Just above the photosphere lies the **[chromosphere](javascript:openGlossaryWnd('e_ga_06_chromospher')" \o "ALT G, Glossary Term, link opens in new window)**, a relatively thin layer of hot gases a few thousand kilometers thick. The chromosphere is observable for a few moments during a total solar eclipse or by using a special instrument that blocks out the light from the photosphere. Under such conditions, it appears as a thin red rim around the sun. Because the chromosphere consists of hot, incandescent gases under low pressure, it produces an emission spectrum that is nearly the reverse of the absorption spectrum of the photosphere. One of the bright lines of hydrogen contributes a good portion of its total light and accounts for this sphere’s red color.



**Figure 14 Chromosphere** The chromosphere is a thin layer of hot gases that appears as a red rim around the sun.

**Corona**

The outermost portion of the solar atmosphere, the **[corona](javascript:openGlossaryWnd('e_ga_06_corona')" \o "ALT G, Glossary Term, link opens in new window)** (*corona* = crown) is very weak and, as with the chromosphere, is visible only when the brilliant photosphere is covered. This envelope of ionized gases normally extends a million kilometers from the sun and produces a glow about half as bright as the full moon.

At the outer fringe of the corona, the ionized gases have speeds great enough to escape the gravitational pull of the sun. The streams of protons and electrons that boil from the corona constitute the **[solar wind](javascript:openGlossaryWnd('e_ga_06_solarwind')" \o "ALT G, Glossary Term, link opens in new window)**. This wind travels outward through the solar system at speeds up to 800 kilometers per second and eventually is lost to space. During its journey, the solar wind interacts with the bodies of the solar system, continually bombarding lunar rocks and altering their appearance. Although Earth’s magnetic field prevents the solar winds from reaching our surface, these winds do affect our atmosphere, as we’ll discuss later.

Studies of the energy emitted from the photosphere indicate that its temperature averages about 6000 K. Upward from the photosphere, the temperature unexpectedly increases, exceeding 1 million K at the top of the corona. Although the corona temperature is much higher than that of the photosphere, it radiates much less energy because of its very low density.

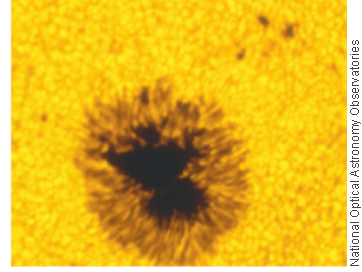
**Reading Checkpoint** (a)What is the solar wind?

**The Active Sun**

The most conspicuous features on the surface of the sun are the dark regions. They were occasionally observed before the advent of the telescope, but were generally regarded as objects located somewhere between the sun and Earth. In 1610, Galileo concluded that these regions were part of the solar surface. From their motion, he deduced that the sun rotates on its axis about once a month. Later observations indicated that not all parts of the sun rotate at the same speed. The sun’s equator rotates once in 25 days, while a location 70 degrees from the solar equator, whether north or south, requires 33 days for one rotation. Imagine if Earth rotated in a similar manner! The sun’s nonuniform rotation is evidence of its gaseous nature.

**Sunspots**

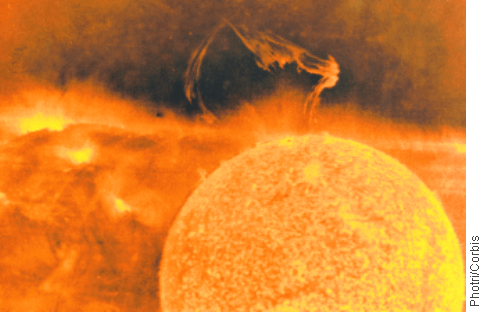
What are those dark areas Galileo observed? The dark regions on the surface of the photosphere are called **[sunspots](javascript:openGlossaryWnd('e_ga_06_sunspot')" \o "ALT G, Glossary Term, link opens in new window)**. As Figure 15 shows, an individual spot contains a black center rimmed by a lighter region. **Sunspots appear dark because of their temperature, which is about 1500 K less than that of the surrounding solar surface.** If these dark spots could be observed away from the sun, they would appear many times brighter than the full moon.

**Figure 15 Sunspots A** Sunspots often appear as groups of dark areas on the sun. **B** A close-up of an individual sunspot shows a black center surrounded by a lighter region.

During the early nineteenth century, it was believed that a tiny planet named Vulcan orbited between Mercury and the sun. In the search for Vulcan an accurate record of sunspot occurrences was kept. Although the planet was never found, the sunspot data revealed that the number of sunspots observable varies in an 11-year cycle.

First, the number of sunspots increases to a maximum, with perhaps a hundred or more visible at a given time. Then their numbers gradually decline to a minimum, when only a few or even none are visible.

**Prominences**

Among the more spectacular features of the active sun are prominences (*prominere* = to jut out). **[Prominences](javascript:openGlossaryWnd('e_ga_06_prominence')" \o "ALT G, Glossary Term, link opens in new window)** are huge cloudlike structures consisting of chromospheric gases. They often appear as great arches that extend well into the corona. Many prominences have the appearance of a fine tapestry and seem to hang motionless for days at a time. Others rise almost explosively away from the sun. These eruptive prominences reach speeds up to 1000 kilometers per second and may leave the sun entirely. **Prominences are ionized gases trapped by magnetic fields that extend from regions of intense solar activity.** Refer to Figure 16.

**Figure 16 Solar Prominence** Solar prominences are huge, arched structures, best observed when they are on the edge of the sun.

**Solar Flares**

The most explosive events associated with sunspots are solar flares. **[Solar Flares](javascript:openGlossaryWnd('e_ga_06_solarflare')" \o "ALT G, Glossary Term, link opens in new window)** are brief outbursts that normally last about an hour and appear as a sudden brightening of the region above a sunspot cluster. **During their existence, solar flares release enormous amounts of energy, much of it in the form of ultraviolet, radio, and X-ray radiation.** At the same time, fast-moving atomic particles are ejected, causing the solar wind to intensify. Although a major flare could conceivably endanger the crew of a space flight, they are relatively rare. About a day after a large outburst, the ejected particles reach Earth, where they can affect long-distance radio communications.

The most spectacular effects of solar flares, however, are the **[auroras](javascript:openGlossaryWnd('e_ga_06_aurora')" \o "ALT G, Glossary Term, link opens in new window)**, also called the northern and southern lights. Following a strong solar flare, Earth’s upper atmosphere near its magnetic poles is set aglow for several nights. The auroras appear in a wide variety of forms, one of which is shown in Figure 17. Sometimes the display looks like colorful ribbons moving with the breeze. At other times, the auroras appear as a series of luminous arcs or as a foglike glow. Auroral displays, like other solar activities, vary in intensity with the 11-year sunspot cycle.

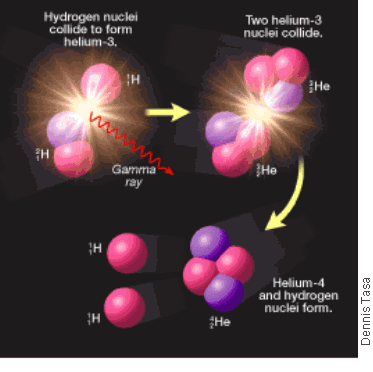
**Figure 17 Aurora Borealis or Northern Lights in Alaska** The same phenomenon occurs toward the south pole, where it is called the aurora australis or southern lights.

**Reading Checkpoint** a)What are solar flares?

**The Solar Interior**

The interior of the sun cannot be observed directly. For that reason, all we know about it is based on information acquired from the energy it radiates and from theoretical studies. The source of the sun’s energy was not discovered until the late 1930s.

**Nuclear Fusion**

Deep in its interior, the sun produces energy by a process known as **[nuclear fusion](javascript:openGlossaryWnd('e_ga_06_nuclearfsion')" \o "ALT G, Glossary Term, link opens in new window)**. This nuclear reaction converts four hydrogen nuclei into the nucleus of a helium atom. Tremendous energy is released. **During nuclear fusion, energy is released because some matter is actually converted to energy, as shown in Figure 18.** How does this process work? Consider that four hydrogen atoms have a combined atomic mass of 4.032 atomic mass units (4 × 1.008) whereas the atomic mass of helium is 4.003 atomic mass units, or 0.029 less than the combined mass of the hydrogen. The tiny missing mass is emitted as energy according to Einstein’s equation:

**Figure 18 Nuclear Fusion** During nuclear fusion, four hydrogen nuclei combine to form one helium nucleus. Some matter is converted to energy.

*E* equals energy, *m* equals mass, and *c* equals the speed of light. Because the speed of light is very great (300,000 km/s), the amount of energy released from even a small amount of mass is enormous.

The conversion of just one pinhead’s worth of hydrogen to helium generates more energy than burning thousands of tons of coal. Most of this energy is in the form of high-energy photons that work their way toward the solar surface. The photons are absorbed and reemitted many times until they reach a layer just below the photosphere. Here, convection currents help transport this energy to the solar surface, where it radiates through the transparent chromosphere and corona.

Only a small percentage of the hydrogen in the nuclear reaction is actually converted to energy. Nevertheless, the sun is consuming an estimated 600 million tons of hydrogen each second; about 4 million tons are converted to energy. As hydrogen is consumed, the product of this reaction—helium—forms the solar core, which continually grows in size.

**Reading Checkpoint** (a)What happens during the process of nuclear fusion?

Just how long can the sun produce energy at its present rate before all of its hydrogen fuel is consumed? Even at the enormous rate of consumption, the sun, shown in Figure 19, has enough fuel to last easily another 100 billion years. However, evidence from other stars indicates that the sun will grow dramatically and engulf Earth long before all of its hydrogen is gone. It is thought that a star the size of the sun can exist in its present stable state for 10 billion years. As the sun is already 4.5 billion years old, it is “middle-aged.

**Figure 19** The sun is the source of more than 99 percent of all energy on Earth.

To initiate nuclear fusion, the sun’s internal temperature must have reached several million degrees. But what was the source of this heat? The solar system is believed to have formed from an enormous compressed cloud of dust and gases—mostly hydrogen. When gases are compressed, their temperature increases. All of the bodies in the solar system were compressed. However, the sun was the only one, because of its size, that became hot enough to trigger nuclear fusion. Astronomers currently estimate its internal temperature at 15 million K.

The planet Jupiter is basically a hydrogen-rich gas ball; if it were about 10 times more massive, it too might have become a star. The idea of one star orbiting another may seem odd, but recent evidence indicates that about 50 percent of the stars in the universe probably occur in pairs or multiples!

**Chapter 24 Section 3 The Sun—Assessment Questions**

# Reviewing Concepts

(1)What is the structure of the sun?

(2)Which layer of the sun can be thought of as its surface?

(4) Are the same number of sunspots always present on the sun? Explain.

(5)How does the sun produce energy?

(6)How much longer will the sun likely exist in its present state?

**Critical Thinking**

(7)**Relating Cause And Effect**Why do sunspots appear dark?

(8)**Applying Concepts**What is the effect on Earth’s atmosphere of a strong solar

flare?

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